Embodied Energy of Rural Houses in Uganda

Nkozi Village Survey

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Introduction

- In East Africa 95% of the population use solid fuels for heating and cooking
- Deforestation in Uganda
  - 44 million tones of wood per annum (equals to 12 toe)
  - Expected to increase up to 135 tones by 2020 in a BAU projection.
  - Burned brick industry accounts of around 6 million tones per annum

Introduction: ELITH Project

- Energy and Low Income Tropical Housing (ELITH) project
  - Seeks to identify, and then propagate, methods of reducing the energy consumption of low-income houses.
- Partners:

UK
- University of Warwick
- University of Cambridge

China
- University of Nottingham

Thailand
- King Mongkut's University of Technology Thonburi (KMUTT)

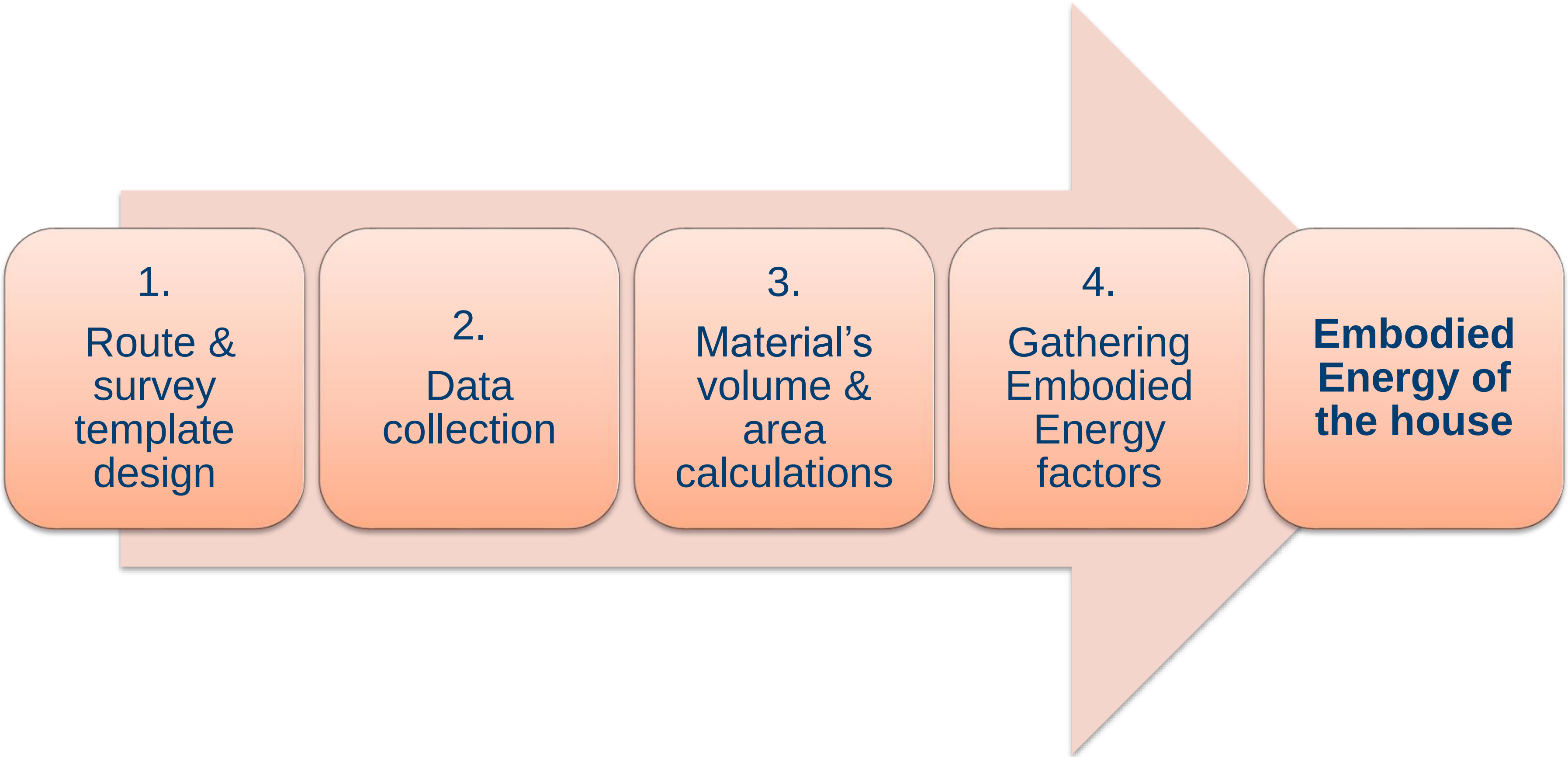
Tanzania
- National Housing and Building Research Agency (NHBRA)

Uganda
- Uganda Martyrs University

Introduction: Aims and Objectives

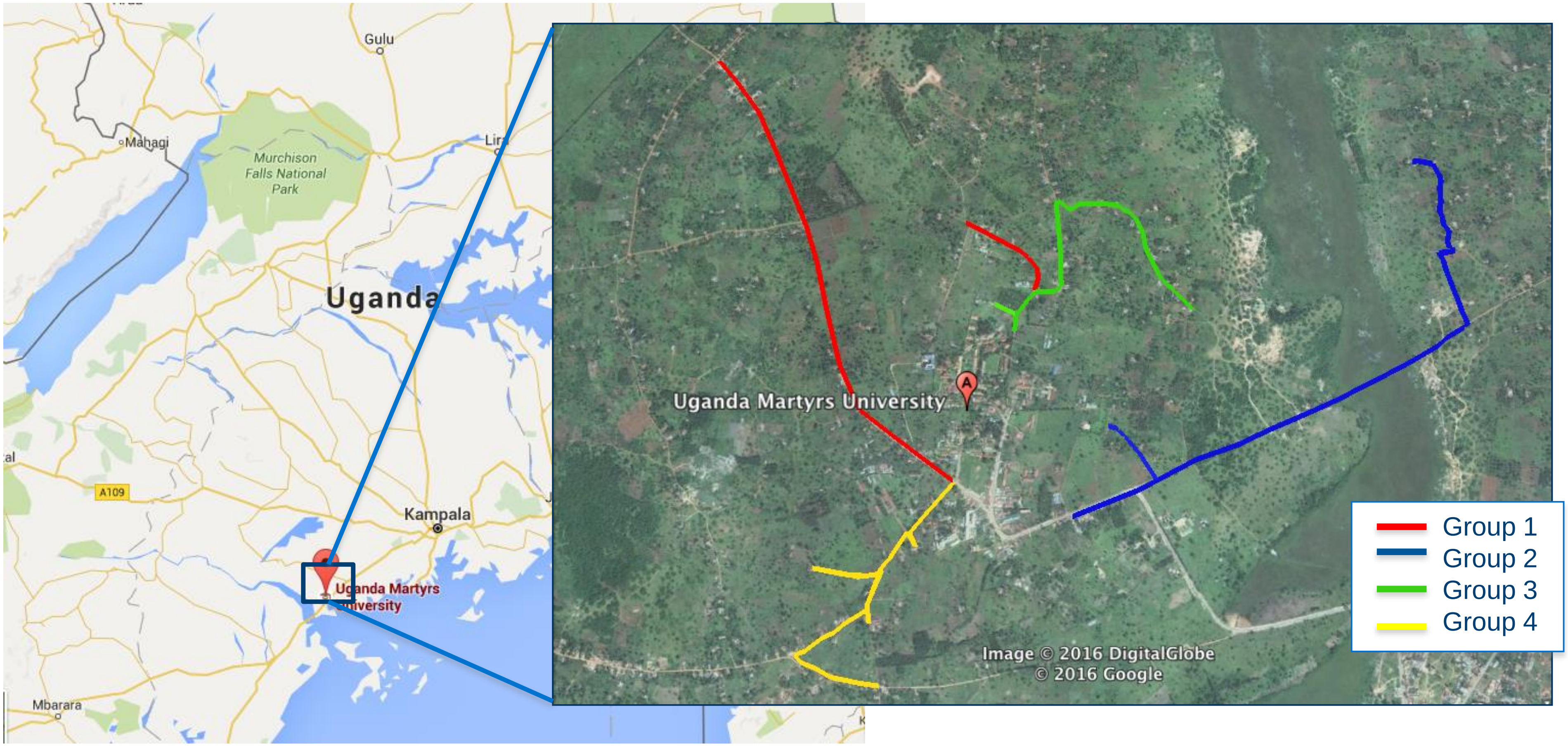
- **Mission to Uganda:**
  - Visit partners and collaborate in dissemination report.
- **Objectives:**
  - Identify embodied and operational energy in low-income houses
  - Identify a low-cost architectural design to minimise energy use
  - Provide support writing the dissemination report

Methodology: Flow chart



Methodology: Route and Survey Template

Nkozi Village



Methodology: Data Collection

- **House measures:**
  - Length, width, height and thicknesses
  - Record of materials used: doors, windows, masonry, floor, roof structure
  - Presence of mortar, plaster, paint, roughcast and ring beam.
- **Household interview:**
  - Ownership
  - Aspirations of refurbishment
  - Energy consumption : wood, charcoal and kerosene
  - Income range

Total sample size = 79 houses

Pollster team

Methodology: Materials' Volume and Area

- **Variables**
  - Volume of bricks [m^3]
  - Volume of mortar [m^3]
  - Volume of plaster [m^3]
  - Area painted [m^2]
  - Area roughcast [m^2]
  - Volume of ring beam [m^3]
  - Volume of roof structure [m^3]
  - Area roof covering [m^2]
  - Volume of floor [m^3]
  - Foundation [m^3]
  - Number and type of doors and windows

Methodology: Embodied Energy Factors

- Embodied Energy of Burned Bricks
  - Produced locally

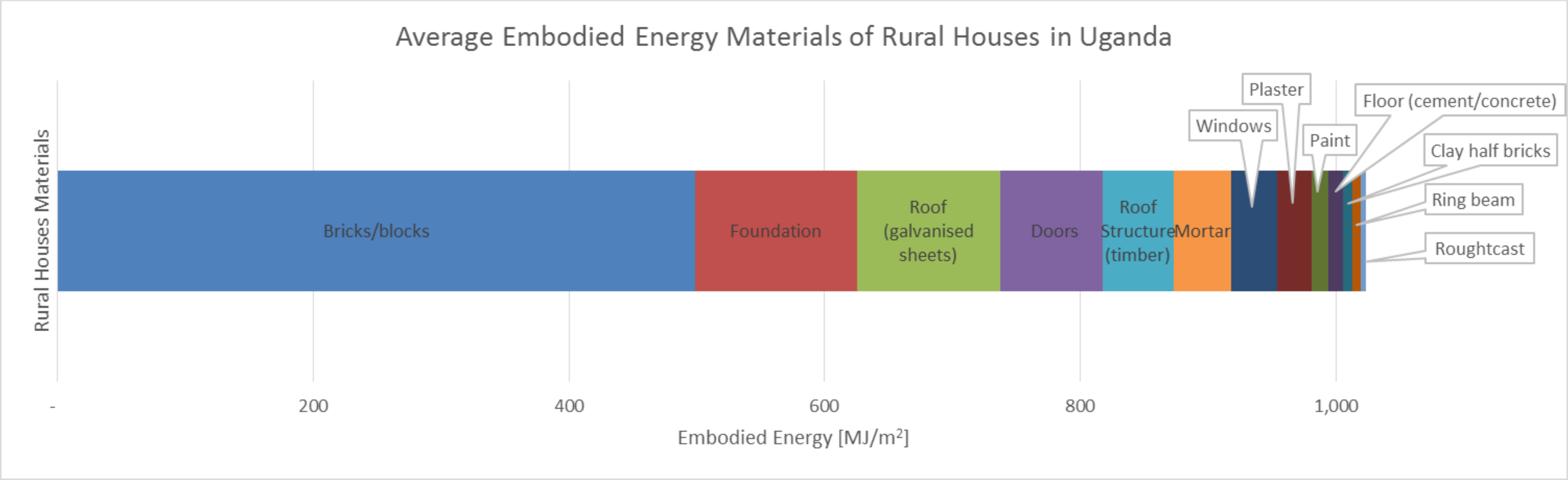
Kiln	Specimen Number	Moisture Content [%]	Wood Calorific Value [MJ/kg]	Wood Consumption [kg]	No Bricks Produced	Brick Embodied Energy [MJ/brick]	Brick Embodied Energy [MJ/m³]
1	2	41%	10,2	8116,2	16180	5,13	2039
2	8	60%	6,0	3869,2	5600	4,15	1650
3	8	41%	10,1	4837,0	5600	8,70	3460
4	6	15%	15,7	9264,9	16000	9,08	3610
5	1	15%	15,7	4916,3	10000	7,71	3065
					Average	**6,95**	**2765**

Benchmarks	Embodied Energy [MJ/brick]	Source
Source 1	39	Hashemi et al. (2015)
Source 2	16	Montgomery & Thomas (2001)
Source 3	6,95	This Research
Source 4	4,25	Esteban & Buccellato (2011)

Methodology: Embodied Energy Factors

			Cradle-to-Gate						
Material	**Description**	**Material**	**Energy Factor**	**Unit**	**Source**	**Density**	**Density units**	**Embodied Energy**	**Embodied Energy Units**
Bricks/Blocks	Concrete Blocks	Block	0,243	[MJ/kg]	Praseeda et al. (2015)	2320	[kg/m3]	**564**	[MJ/m3]
	Half Clay bricks	Half brick	1,270	[MJ/kg]	Praseeda et al. (2015)	1435	[kg/m3]	**1822**	[MJ/m3]
	Steel reinforced concrete	Concrete	0,243	[MJ/kg]	Praseeda et al. (2015)	2320	[kg/m3]	**564**	[MJ/m3]
		Steel	25,3	[MJ/kg]	ICE 2.0	7800	[kg/m3]	**197340**	[MJ/m3]
	Burned Clay Brick	Clay Brick	2765	[MJ/m^3]	Own research	1441	[kg/m3]	**2765**	[MJ/m3]
Mortar	5:1 volumetric, sand and cement	Sand	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**411**	[MJ/m3]
		Cement CEM II/B-V	4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Plaster	3:1 volumetric, sand and cement	Sand	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**409**	[MJ/m3]
		Cement CEM II/B-V	4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Paint	Single coat paint	General Paint	10,5	[MJ/m^2]	ICE 2.1			**10,5**	[MJ/m2]
Roughtcast	2:1 volumetric, sand and cement	Sand	0,97	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**613**	[MJ/m3]
		Cement CEM II/B-V	4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Ring beam	2:4:1 volumetric. Sand, aggregates and cement	Sand	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**444**	[MJ/m3]
		Aggregates	0,083	[MJ/kg]	ICE 2.0	1602	[kg/m3]		
		Cement CEM II/B-V	4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Roof timber	Swan softwood	Sawn Softwood	7,4	[MJ/kg]	ICE 2.0	483	[kg/m3]	**3574**	[MJ/m3]
Roof steel sheet	Galvanised corrugated steel sheets	Steel Sheet	28,5	[MJ/kg]	ICE 2.0	3,13	[kg/m2]	**89**	[MJ/m2]
Foundation concrete	3:4:1 volumetric. Sand, aggregate and cement	Sand	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**108**	[MJ/m3]
		Aggregates	0,083	[MJ/kg]	ICE 2.0	1602	[kg/m3]		
		Cement CEM II/B-V	0,7	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Foundation wall	3:1 volumetric mortar and bricks. Sand and cement.	Mortar: sand and Cement CEM II/B-V	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**409**	[MJ/m3]
			4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
		Brick	2765	[MJ/m^3]	Own research	2765	[MJ/m3]	**2765**	[MJ/m3]
Floor	4:1 volumetric, sand and cement	Sand	0,0081	[MJ/kg]	ICE 2.0	1602	[kg/m3]	**410**	[MJ/m3]
		Cement CEM II/B-V	4,065	[MJ/kg]	ICE 2.0	1506	[kg/m3]		
Door Timber		Sawn Softwood	154	Door	ICE 2.0 & Own R.			**154**	[MJ/door]
Door Steel		Steel	3755	Door	ICE 2.0 & Own R.			**3755**	[MJ/door]
Door Timber+Glass		Timber	103	Door	ICE 2.0 & Own R.			**150**	[MJ/door]
		Glass	46,8	Door	ICE 2.0 & Own R.				
Door Steel+Glass		Steel	2524	Door	ICE 2.0 & Own R.			**2570**	[MJ/door]
		Glass	46,8	Door	ICE 2.0 & Own R.				
Window Timber		Timber	81,4	Window	ICE 2.0 & Own R.			**81**	[MJ/window]
Window Steel		Steel	1973	Window	ICE 2.0 & Own R.			**1973**	[MJ/window]
Window Timber+Glass		Window	199	Window	ICE 2.0 (or 77.1MJ own R.)			**199**	[MJ/window]
Window Steel+Glass		Steel	631	Window	ICE 2.0 & Own R.			**682**	[MJ/window]
		Glass	51	Window	ICE 2.0 & Own R.				

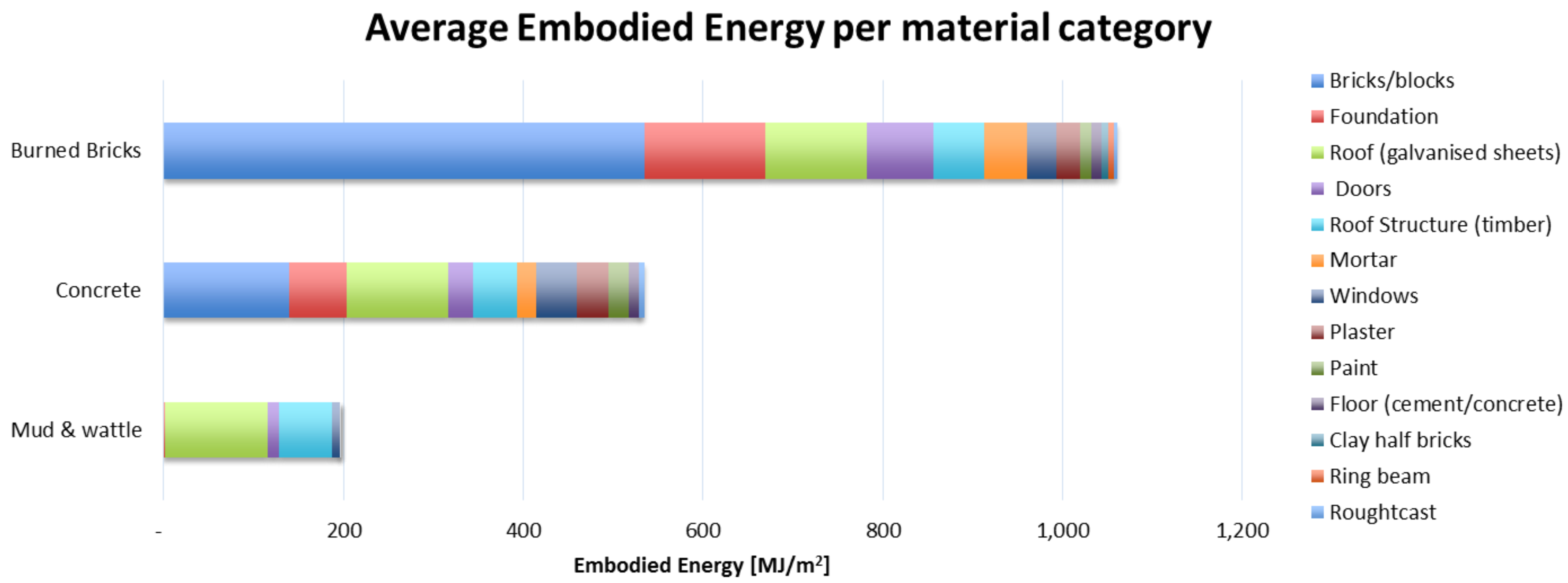
Results



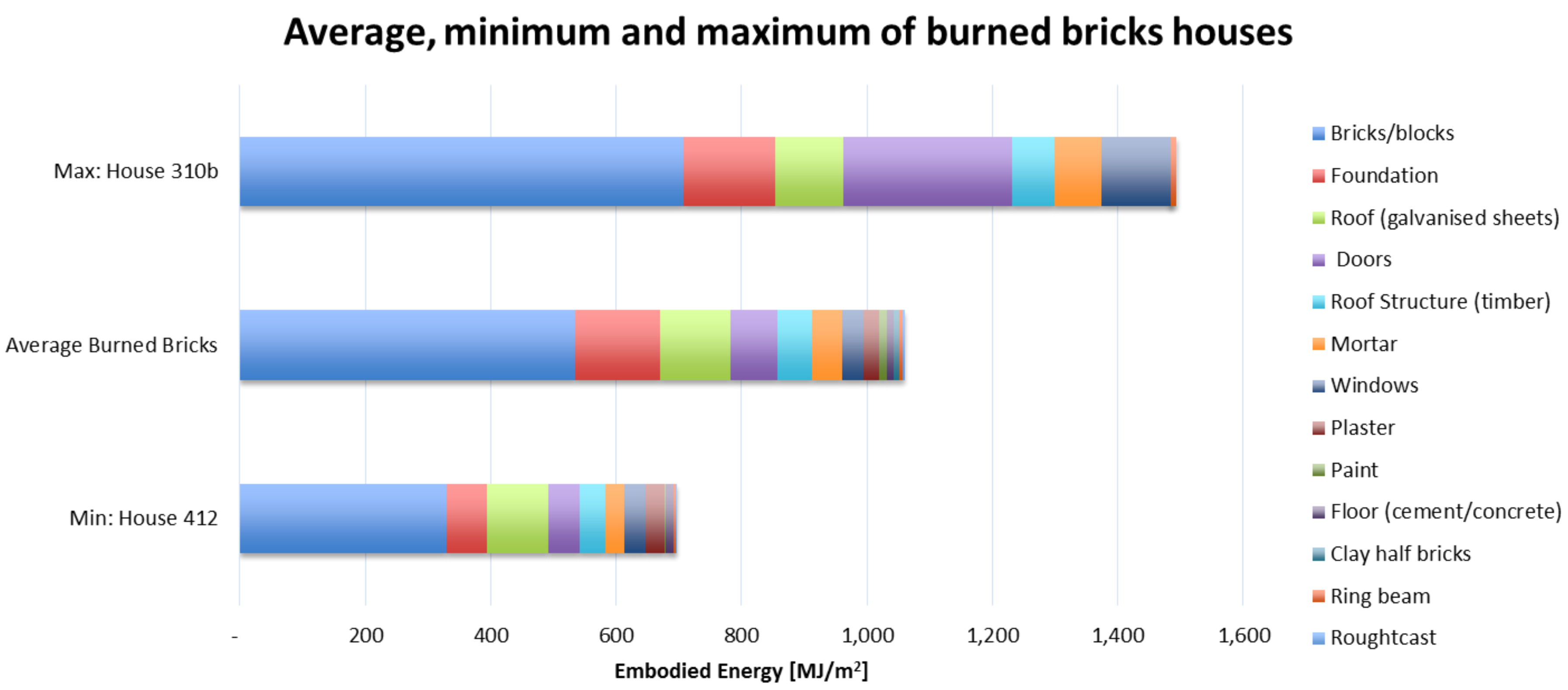
Average Embodied Energy Materials of Rural Houses in Uganda
Rural Houses Materials
Bricks/blocks
Foundation
Roof (galvanised sheets)
Doors
Roof Structure (timber)
Mortar
Windows
Plaster
Paint
Floor (cement/concrete)
Clay half bricks
Ring beam
Roughtcast
-
200
400
600
800
1,000
Embodied Energy [MJ/m2]

Results: Embodied Energy Material Category

Burned Bricks	Concrete	Mud & wattle
90%	5%	5%



Results: Embodied Energy Burned Bricks

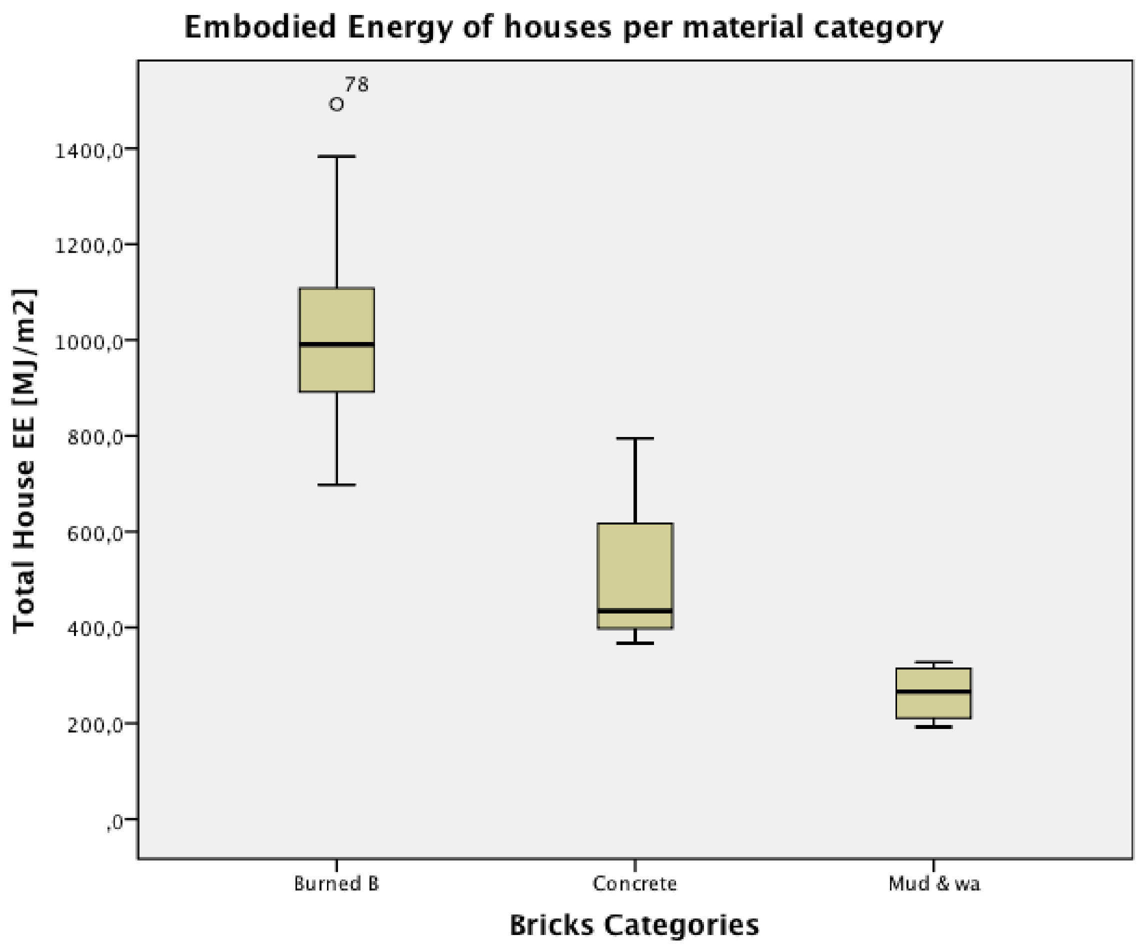


Results: Embodied Energy Burned Bricks

House 310b

House 412

Results: Statistics



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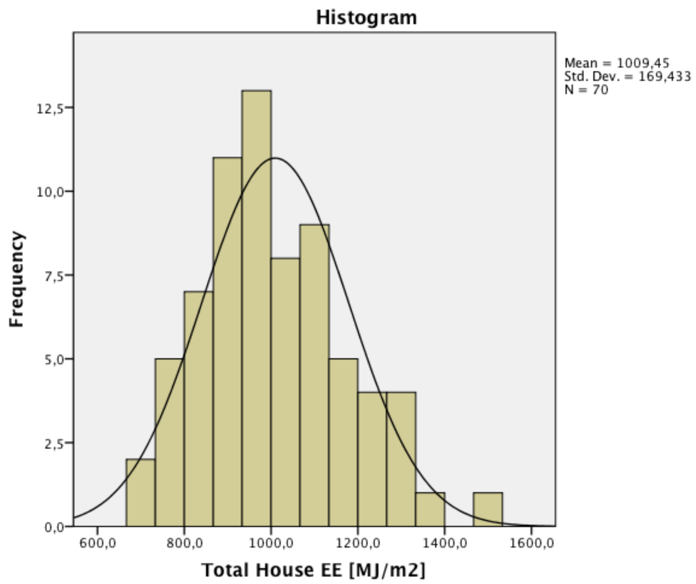
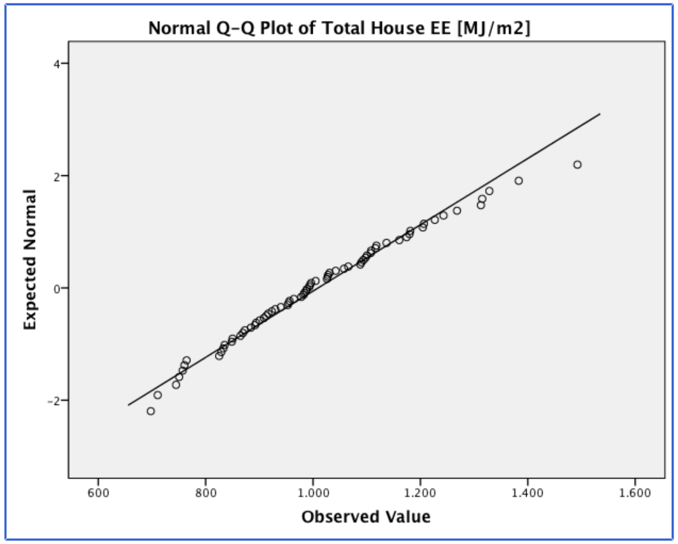
Results: Burned Bricks Statistics





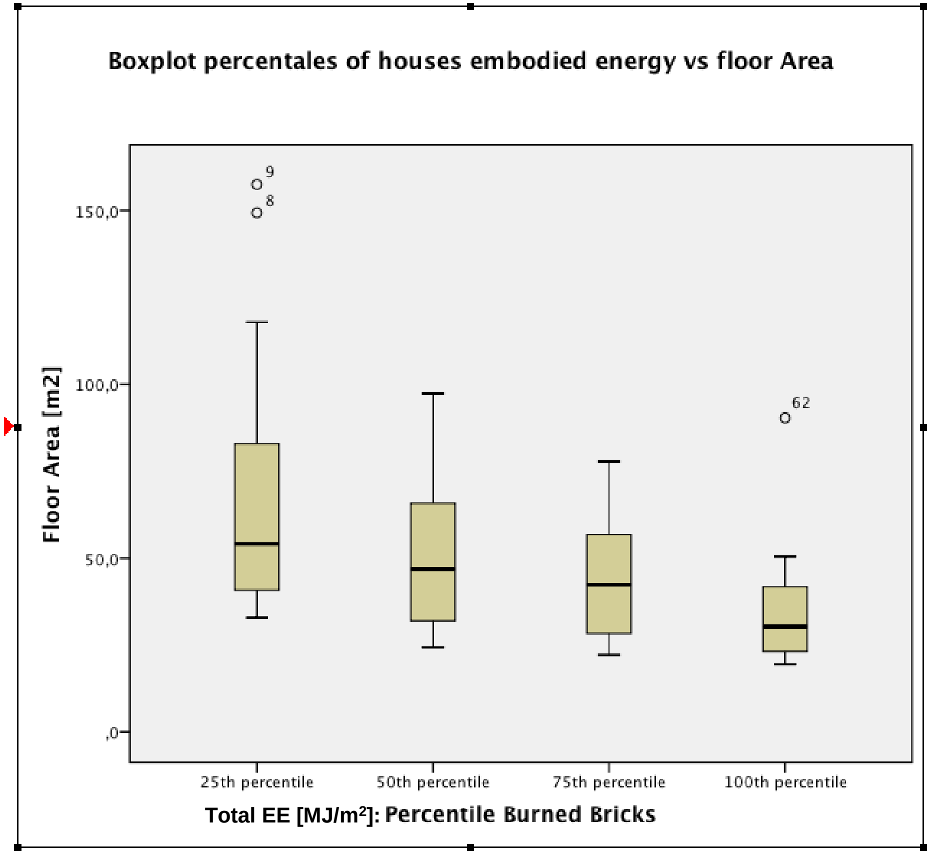
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Total House EE [MJ/m2]	,074	70	,200*	,982	70	,396

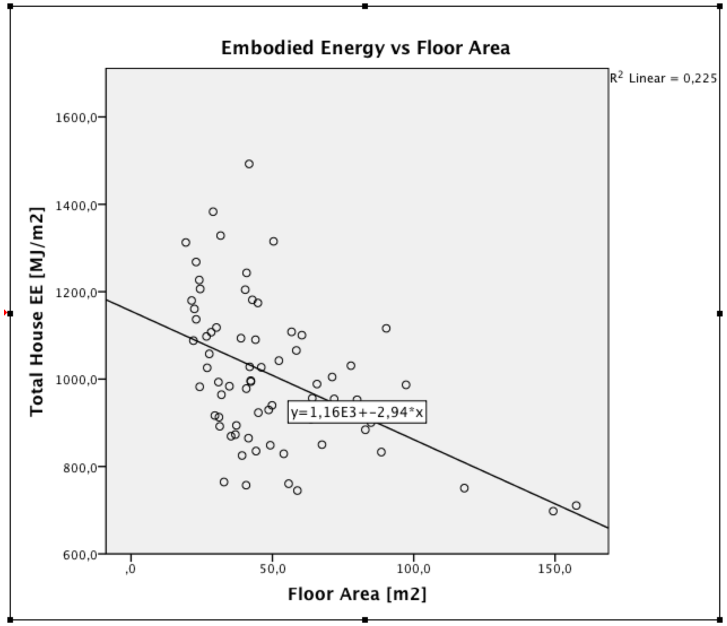
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Results: Burned Bricks Statistics



	House 412	House 310b
Floor Area [m²]	149	41,8



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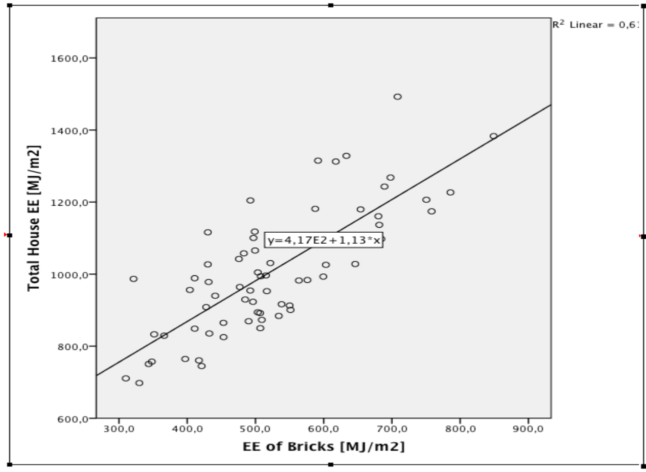
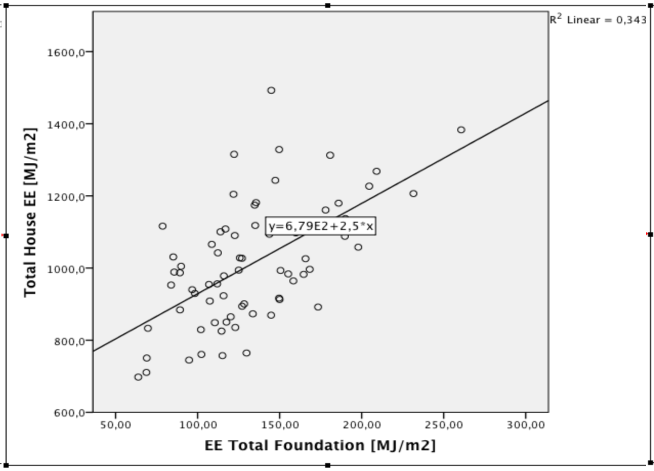
Results: Burned Bricks Statistics

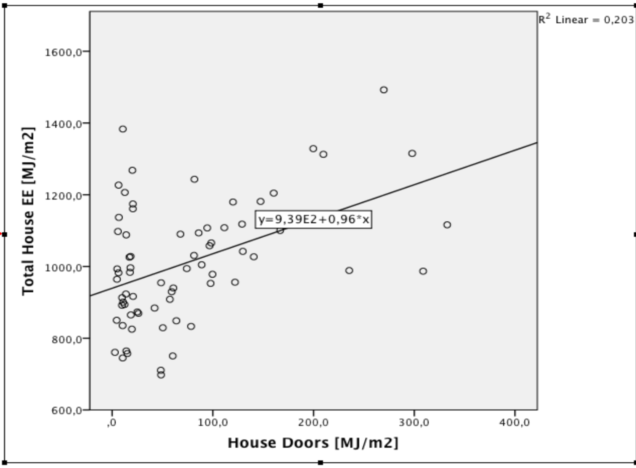
Total EE vs Burned Bricks



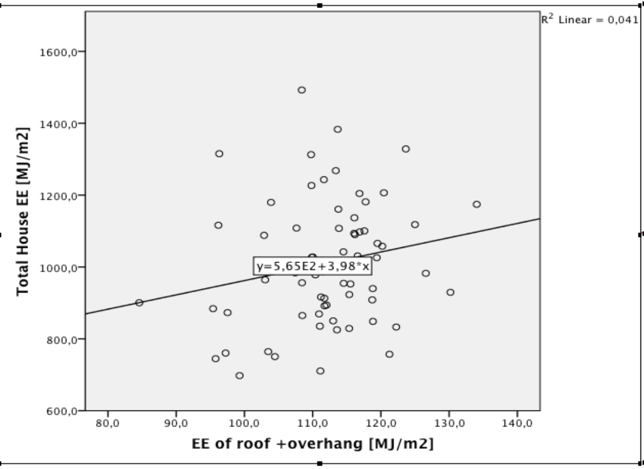
Total EE vs Foundation



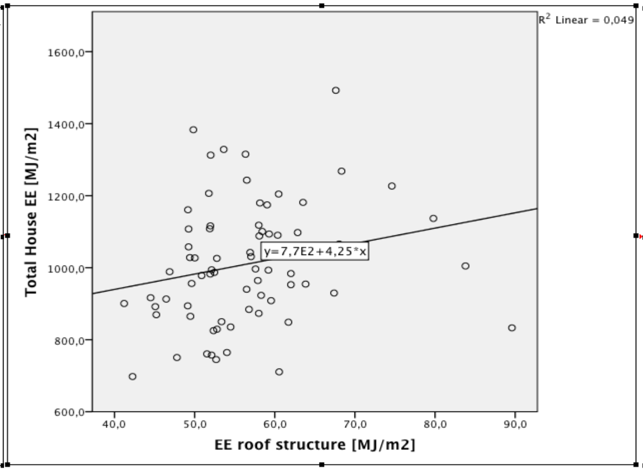
Total EE vs Doors



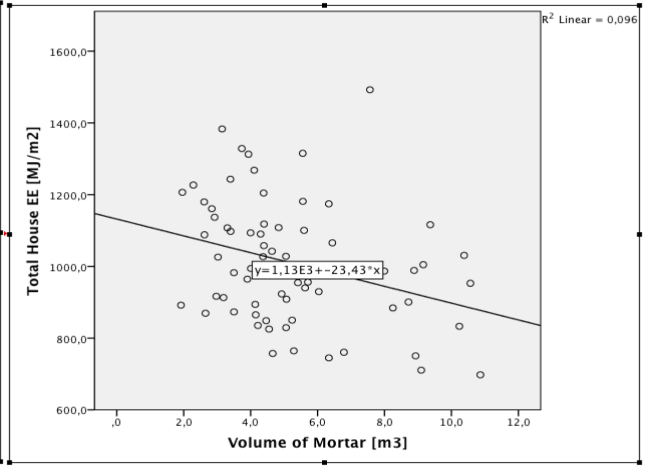
Total EE vs Roof Covering



Total EE vs Roof Structure



Total EE vs Mortar



Results: Evaluating ISSB instead Burned Bricks

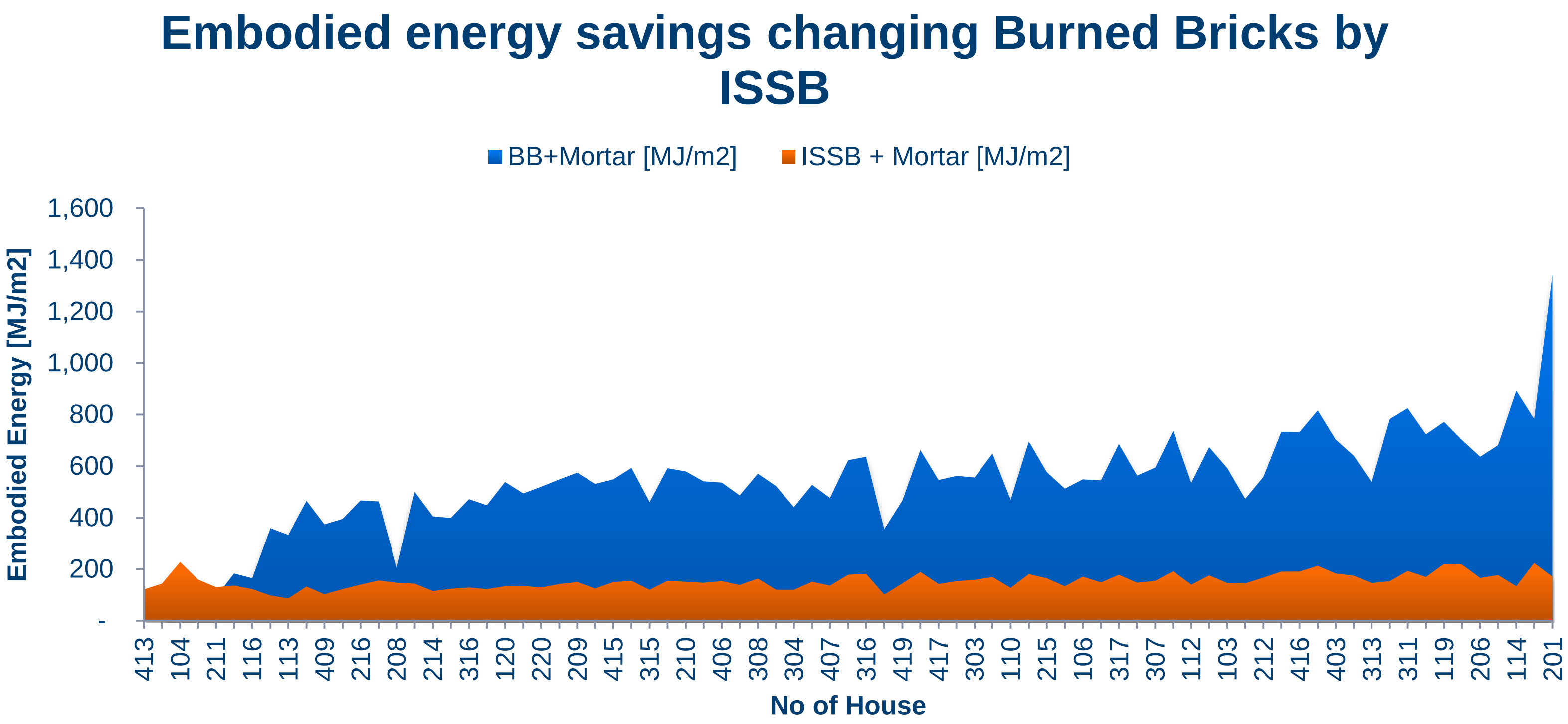
Interlocking Stabilised Soil Blocks (ISSB)

Characteristics	ISSB	Burned Bricks
Size [mm]	266x140x95[1]	221x121x94**
Compression Strength [N/mm^2]	2.5 – 6.7[2]	5.9 – 7**
Price [UGX]	300[1]	120**
Density [kg/m^3]	1700[1]	1441**

** This research
[1] Perez-Peña (2009)
[2] Walker (2007) and Odongo (2008)

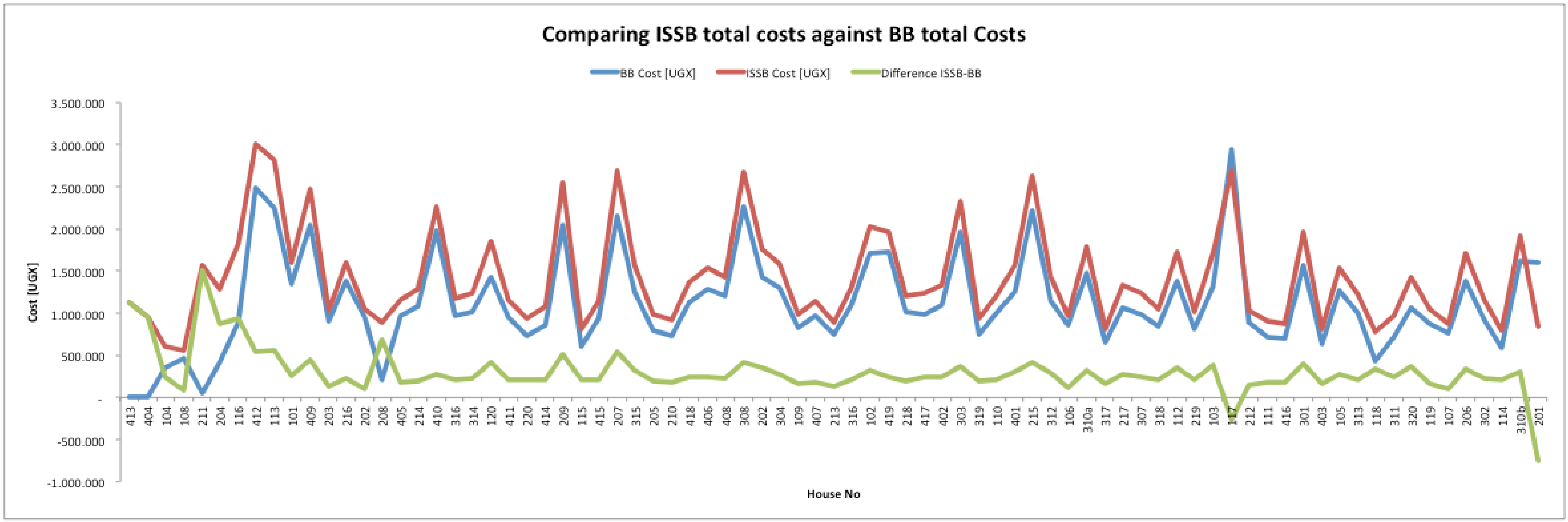
Source: M. M. Nambatya (2015)

Results: Evaluating ISSB vs Burned Bricks



Results: Evaluating ISSB vs Burned Bricks

- Material costs



£1= UGX 4,798

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Limitations

- No permission to enter to houses:
  - Estimation of roof structure
  - Estimation of interior layout
- Lack of embodied energy factors for African/Ugandan building materials
- Errors on measures taken
- Foundations cannot be seen

Conclusions

- Change burned bricks by ISSB means high energy savings per slightly higher investment. However, by using ISSB plaster, paint and roughcast are not necessary.
- As expected, correlation was found between Burned Bricks and the total embodied energy of houses, but no clear correlation was shown for the other variables.
- Deeper statistic analysis is needed to know the influence of each variable on embodied energy results

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Thank you!!